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Dichotomy of mangrove management: A review of research and policy in the Mesoamerican reef region

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ABSTRACT

Mangroves are declining globally at faster rates than tropical forests and coral reefs, with primary threats including, aquaculture, agriculture and climate change. Mangroves provide ecosystem services to coastal communities of Mexico, Belize, Guatemala and Honduras, which comprise the Mesoamerican Reef (MAR) ecoregion. Over the past two decades mangroves within the MAR have declined. Current estimates of mangrove cover in the region suggest that mangroves cover 239,176 ha of the MAR, equivalent to 1.7% of the world's mangroves. Concerted efforts to manage, conserve and protect mangrove forest are apparent in all four countries. Comprehensive laws that prohibit the cutting and clearing of mangroves have been implemented in Mexico, Guatemala and Honduras. Belize has a permitting system to regulate mangrove alterations. In addition, a total of seven international and regional agreements have been ratified. Across the ecoregion, forty-three protected areas have been designated that contain mangroves, providing protection to 111,396 ha of mangroves (47% of the total). However, our findings suggest a lack of transparency in the governance framework, a disconnect between management and research, and geopolitical differences have all played a role in reducing management efficacy. A key finding of our study reveals a distinct division in the perceived major threats to mangroves between Ramsar site managers and researchers. Ramsar site managers identify anthropogenic disturbances as key threats, while in contrast, the bulk of research focuses on natural disturbances. To promote the inclusion of evidence-based research within mangrove management plans, greater efforts to connect these important stakeholders are required.

1. Introduction

Mangroves are a diverse group of halophytic plant species, which form highly productive forests in the area between mean sea level and the highest spring tide mark along tropical and sub-tropical coastlines and estuaries (Tomlinson, 1994). Once perceived as mosquito infested wastelands, mangroves have now been recognized as highly productive and ecologically important ecosystems. Providing ecosystem services to marine and terrestrial environments, and human societies (Gilman et al., 2008; Nagelkerken et al., 2008), which are valued at US $9900–35,900 $ha^{-1}yr^{-1}$ (Costanza et al., 1997; Sathirithai and Barbier, 2001; Barbier, Hacker, Kennedy, Kock, Stier, 2011). Some of the most important mangrove ecosystem services include: coastline protection (in particular storm, hurricane and tsunami protection); waste water treatment; production of extractable materials; and provision of cultural sites (Rönnbäck et al., 2007; Warren-Rhodes et al., 2011). Despite the known value of these forests, mangroves are highly threatened. Deforestation estimates suggest mangrove cover has declined by 30–86% since the mid 1990's (Duke et al., 2007), and mangroves continue to decline globally at unprecedented rates (FAO, 2007). Globally the main threats to mangrove forests include: coastal development; logging for timber and fuel; aquaculture; salt extraction; and agriculture (Valiela et al., 2001; Alongi, 2002; Rönnbäck et al., 2007). The additional threats of climate change, e.g. sea-level rise, are also of concern (Schaeffer-Novelli et al., 2016; Short et al., 2016). Understanding if or how mangroves can adapt to such changes is of particular relevance to already threatened ecosystems, e.g. in the Caribbean (Godoy and De Lacerda, 2015; Sasmito et al., 2016).

The majority (over 70%) of mangroves are located within developing countries (Giri et al., 2011), where limited resources and capacity can inhibit effective management. At the international level, a number of treaties and conventions afford some protection to mangroves (Macintosh and Ashton, 2002), for example: the Ramsar Convention (1974); the Cartagena Convention (1983); and the International Tropical Timber Agreement (2011). However, few of these treaties provide any effective legal protection and none of them address the

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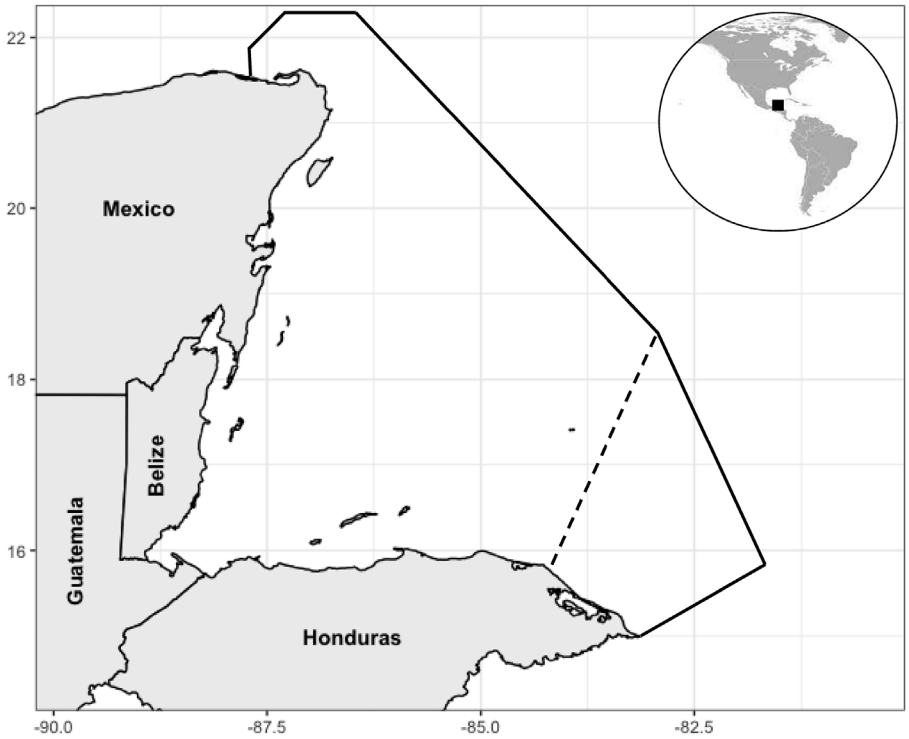

Fig. 1. Map of the Mesoamerican Reef Eco-region. Solid line highlights the area included within the study, the official boundary of the MAR (dotted line) does not include the eastern north shore of Honduras.

conservation, preservation, or management of a particular mangrove species (Polidoro et al., 2010). National legislation pertaining to mangrove management in the 1960's was primarily focused on mangrove exploitation (Carter et al., 2015). However, over the past five decades management has progressed which has led to the integration of mangroves into coastal zone management plans (Carter et al., 2015).

Common tools for the preservation and management of mangrove and other marine ecosystems include: marine protected areas (MPA's); nature reserves; wilderness areas; national monuments and national parks. Since 1974, increasing protection has been provided through Ramsar site designation. To date, 281 Ramsar sites (12.5% of all Ramsar sites) are intertidal forested wetlands, which includes mangrove forests (www.ramsar.org). Although increased recognition of mangroves in management plans is encouraging, the majority of plans associated with MPA's and Ramsar sites are based on generalized characteristics and threats, with limited reference to prior scientific research. In fact, there appears to be no effective mechanism for creating links between management activities for, and scientific research on, mangroves, thus research is rarely incorporated into management plans. Similar observations have been made in the management of coral reef ecosystems, where a mere 14% of information cited in management plans for the reefs of Australia, Kenya and Belize was primary research (Cvitanovic et al., 2014). In this case, research was deemed to be inaccessible to managers due to, long publication times, subscription only access to research and poor articulation of management implications of the research (Cvitanovic et al., 2014). Yet, for effective management to take place, evidence based decision-making is critical (Christensen et al., 1996; Ruckelshaus et al., 2008).

In this article we use the Mesoamerican reef (MAR) ecoregion as a case study, to examine the current status of mangroves, the legislation implemented to protect, manage and conserve mangroves, and review peer-reviewed scientific outputs from the region. The aim of this paper is to understand the current management paradigms within the MAR and identify threats to mangroves within the region. We compare the foci of management strategies and research programs in order to determine where overlap occurs and where there are gaps in the knowledge base.

2. Methods

2.1. Study area

We have chosen to focus on the Mesoamerican Reef (MAR) ecoregion because the majority of mangrove research is concentrated in South-East Asia, where larger and more diverse stands of mangroves are located (Saenger, 2002). Much less is known about these ecosystems in Latin America and the Caribbean (but see, Ellison and Farnsworth, 1997; Núñez-Farfán et al., 2002; Ellison, 2004). The MAR ecoregion extends over 1000 km from the Yucatan peninsula, Mexico (21.56°N; 087.09°W) to the east coast of Honduras (14.97°N; 083.16°W), encompassing the Caribbean coastlines, open-ocean, networks of cays, and offshore banks of Mexico, Belize, Guatemala and Honduras (Kramer and Kramer, 2002) (Fig. 1). It is home to the largest barrier reef in the western hemisphere and supports the livelihoods of approximately two million people (Kramer and Kramer, 2002), of particular importance are the fishing (Box and Canty, 2010) and tourism industries (Doiron and Weissenberger, 2014). Considerable attention has been given to coral reefs in the region, however seagrass and mangrove ecosystems have often been overlooked. In this review we consider the entire Honduran north shore as part of the MAR ecoregion, due to potentially high levels of connectivity between the Honduran east coast and the MAR (Butler et al., 2011; Truelove et al., 2015; Chollett et al., 2017). The boundaries of the ecoregion were originally defined by the presence of several physiogeographic boundaries, these include the Gulf of Mexico, strong oceanic currents between the Yucatan peninsular, Mexico and south west Cuba, the shallow waters of the Nicaraguan rise, Honduras, in addition to a number of terrestrial environmental variables, e.g. rainfall. The ecoregion was officially declared in 1997 as part of the Tulum agreement, where all four counties came together recognizing the importance of the region and the need to jointly manage a

shared marine resource (Kramer and Kramer, 2002).

2.2. Mangrove cover estimations

First, we estimated mangrove forest cover for each country across the region. The three true mangrove species: *Rhizophora mangle; Avicennia germinans* and *Laguncularia racemosa* are considered as part of the mangrove forest system in all four countries. However, the mangrove associate *Conocarpus erectus* (Buttonwood mangrove) is only defined as part of the mangrove forest in Guatemala and Honduras. Regardless of a country's definition of the mangrove complex, mangrove cover estimates herein include all four species. Country specific estimates of mangrove cover were taken from the most recent estimates available (Mexico (Rodríguez-Zúñiga et al., 2013), imagery from 2010; Belize (Cherrington et al., 2010), imagery from 2010; Guatemala (MARN, 2013), imagery from 2010; and Honduras (Carrasco and Caviedes, 2014), imagery from 2008 to 2010).

2.3. Mangrove management plans

To ascertain the level of management and protection directly focused on mangroves in each country, we first reviewed national environmental legislation, using Google searches and accessing management plans. We subsequently identified which international and regional conventions and agreements relating to mangroves each country has signed or ratified. Within the Caribbean, protected areas that contain mangroves include Ramsar sites and Marine Protected Areas (MPAs). Ramsar sites that contain mangroves were identified through the American Ramsar Secretariat (Pers. Comms.) and the Ramsar website (www.ramsar.org). The Healthy Reefs for Healthy People Initiative (HRI; www.healthyreefs.org) provides the names of all of the MPAs within the MAR, which have marine territory, and provides the associated management plan. If a managment plan was not available on the HRI website a wider web search was conducted, if after the search we did not identify a management plan we assumed that one did not exist or is not publicly available. Web searches (in English and Spanish), were used to identify management plans for each of the named protected areas. Management plans for protected areas, where available, were downloaded and searched using the keywords mangroves (mangr*) in English, and manglar (mangl*) in Spanish to find explicit references to the management of mangroves. It must be noted that the most recent management plans were used in this review and that management plans within the region are generally designed for a five-year period. In many cases the management period had expired, but we assume that current management strategies are based on the most recent plans.

2.4. Scientific literature review

To determine the focus of scientific research on mangroves in the MAR, peer-reviewed scientific publications were searched for using the Boolean search methodology. Multiple combinations of the following keywords (and their equivalents in Spanish) were used in the search: 'Mangrove'; '*Rhizophora*'; '*Avicennia*'; '*Laguncularia*'; '*Conocarpus*'; 'Mesoamerica'; 'MBRS'; 'MAR'; 'Caribbean'; 'Mexico'; 'Belize'; 'Guatemala'; and 'Honduras'. Only articles published from 1997 to date were used, as this date coincides with the declaration of the MAR as an ecoregion by all four countries, and therefore to the direct management of the ecoregion. Books or book sections were not used, as we could not be sure of the peer-review process, and reviews were not included. Methodologies of articles were examined to ensure that research occurred in at least one of the four MAR countries and within the boundaries of the MAR ecoregion, as we delimited it. A total of 81 peer-reviewed publications (see supplementary materials for a full list of publications) were identified and the research undertaken in each country was tallied. Where research occurred in multiple countries in a single paper, each country received a tally.

2.5. Identification of threats

A fine scale analysis of articles that were identified to focus on threats to mangroves was conducted to categorize the type of threat. Eight different threats were identified, a total of 29 times, and each threat was categorized as either natural or anthropogenic disturbances. *Natural disturbances* were: hurricanes; sea-level change; light gaps; seismic activity; tsunamis; and subsidence. *Anthropogenic disturbances* were: commercial development and deforestation. Threats identified were tallied and a proportion of each threat category was calculated based on the total number of threats identified.

A list of threats to Ramsar sites was obtained from the American Ramsar Secretariat. The threats were identified by future managers of Ramsar sites from a list of 51 options supplied by Ramsar (see supplementary materials for the full list of threats and their definitions) during the Ramsar site application process. The list of threats provided was pre-defined, and as a result not all threats reported may be relevant to the protected area, e.g. in Guatemala 'agriculture and aquaculture' was a reported threat. However, aquaculture is currently not present in the Guatemalan Caribbean, in contrast agriculture is present and is considered a threat to mangroves.

Thirty-seven different threats were identified by Ramsar managers, across the four countries, a total of 236 times, with a maximum of twenty-two at a single site. We categorized threats as either natural disturbances or anthropogenic disturbances. *Natural disturbances* were: storms and flooding; fire and fire suppression; problematic native species; invasive and other problematic species and genes; climate change and severe weather; and invasive non-native/alien species. *Anthropogenic disturbances* were: biological resource use; human settlements (non-agricultural); tourism and recreation areas; housing and urban areas; fishing and harvesting aquatic resources; natural system modifications; agriculture and aquaculture; pollution; logging and wood harvesting; human intrusions and disturbances; hunting and collecting terrestrial animals; vegetation clearance/land conversion; recreational and tourism activities; gathering terrestrial plants; transportation and service corridors; water regulation; household sewage; livestock farming and ranching; urban waste water; agriculture and forestry effluents; drainage; dams and water management/use; energy production and mining; unspecified development; wood and pulp plantations; mining and quarrying; industrial and military effluents; water abstraction; garbage and solid waste; shipping lanes; and airborne pollutants. Individual threats that were reported were tallied as either natural or anthropogenic disturbances, a proportion of each threat category was calculated from the combined number of threats identified.

3. Results

3.1. Mangrove cover

Mangrove cover in the MAR is estimated at 239,176 ha, cover has declined across the region since the 1990's, where mangroves covered approximately 350,000 ha (Fig. 2), a loss of over 110,000 ha in a twenty-year period. Proportional cover of mangroves in the MAR region varies considerably between and within the four countries. The majority of mangrove cover within the MAR is located along the Yucatan Peninsula, Campeche and Quintana Roo regions of Mexico (53.5%; 128,049 ha; Fig. 2), however Mexico has significantly greater mangrove cover in the Gulf of Mexico and on the Pacific coastlines. Belize is the only country to have its entire coastline in the MAR, and approximately one third of mangrove cover of the MAR is found in Belize (31.2%; 74,684 ha; Fig. 2). Only a small fraction of the total mangrove cover of the region is located in Guatemala (0.5%; 1170 ha; Fig. 2), the majority of Guatemalan mangroves are located on the Pacific coast. Despite the

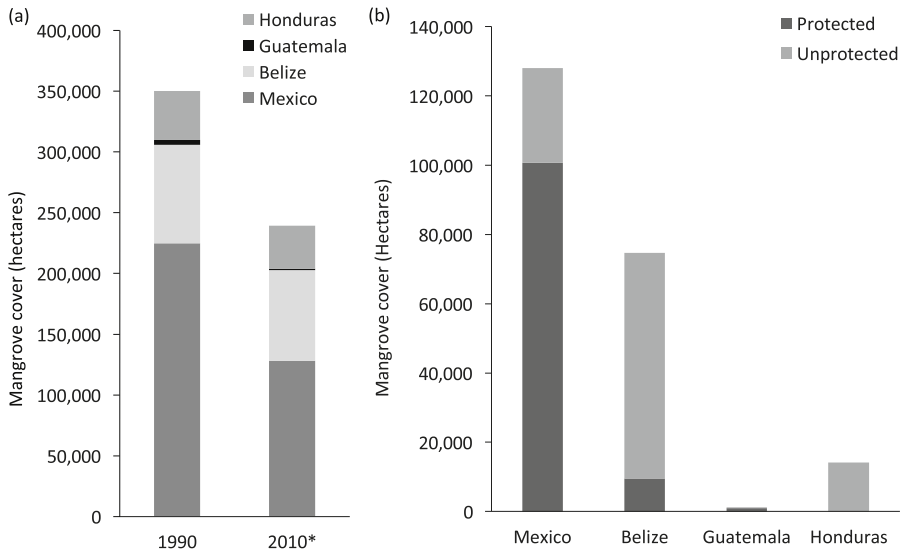

Fig. 2. Mangrove cover within the MAR region. (a) Historical (Kramer and Kramer, 2002) and recent estimations of mangrove cover. (b) Total mangrove cover in each of the four MAR countries, with hectares of protected and unprotected mangrove highlighted. (Mexico (Rodríguez-Zúñiga et al., 2013); Belize (Cherrington et al., 2010); Guatemala (MARN, 2013); Honduras (Carrasco and Caviedes, 2014). *Some data from Honduras is from 2008.

size of its coastline, mangrove cover in Honduras is a small proportion of the MAR total (14.7%; 35,273 ha; Fig. 2). Mangrove cover in Honduras is almost equally divided between the Caribbean and Pacific coasts.

3.2. Legislation and management

Comprehensive legislation exists within the region to protect mangroves. In Mexico, Guatemala and Honduras, mangroves are property of the state and stringent laws exist which prohibit the removal and cutting of mangroves and prevent changes in land use (Table 1). In contrast, the majority of Belizean mangroves are privately owned and only 30% are state owned. However, national legislation in Belize is applicable to all mangroves regardless of ownership. Within Belize, the cutting and clearance of mangroves is controlled by a permitting system, however the dredging and landfill of mangroves is only permitted under exceptional circumstances.

At the international level, the four countries of the MAR have ratified a total of seven international conventions and agreements to promote the management and sustainable use of marine and wetland resources (Table 1). The most important of these for mangroves is the Ramsar (wetlands) convention. Geopolitical differences influence regional cooperation, e.g. Mexico, a North American country, is excluded from Central American agreements, and Belize with a British rather than Spanish colonial heritage exhibits preferences with Caribbean Community agreements. All four countries are parties of the two main international conventions that are relevant to environmental protection: the Cartagena convention and Ramsar convention (Table 1). Honduras is the only country not to have ratified the Cartagena convention, but is a signatory to the convention. Additionally, all four countries ratified the Tulum declaration and the subsequent Mesoamerican barrier reef system project (www.mbrs.doe.gov.bz).

We identified a total of 43 protected areas in the MAR which have mangroves within their boundaries (Table 2), and estimate that just under half (46.6%; 111,396 ha) of the mangroves in the MAR are within the boundaries of a protected area (Fig. 2). Over two thirds (31) of the protected areas have management plans (Table 2), although implementation of these plans may vary. The majority of management plans had no specific management strategies for mangroves, other than a reference to the national legislation, in the few instances where strategies were stated they were related to mangrove restoration, e.g. Shipstern Conservation and Management Area, Belize.

In Mexico, mangroves are the responsibility of the Department of Ecology and Environment, and the Institute for Flora, Fauna and Culture within the Secretariat of the Environment and Natural Resources. In addition, the National Commission for Natural Protected Areas (CONANP) assumes responsibility for mangroves when they are located within a protected area. CONANP may co-manage protected areas with a local non-governmental organization (NGO). We identified 13 protected areas that contain mangroves in Mexico, these areas provide protection to approximately 80% (100,764 ha) of Mexican mangroves forests in the MAR (Table 2; Fig. 2).

In Belize, the Forestry Department within the Ministry of Agriculture and Fisheries is responsible for managing Belizean mangroves. The Coastal Zone Management Authority and Institute and Fisheries Department may also assume a management role. NGO's co-manage a number of protected areas in Belize and therefore assume a direct role in the management of mangroves. Private protected areas are increasingly popular, and these areas are coordinated by the Belize Association of Private Protected Areas. We were not able to identify any private protected areas that provided protection to mangroves. Only a small proportion (12.9%) of the total mangrove cover of Belize is located within the 15 protected areas (Table 2; Fig. 2).

Mangroves in Guatemala are the responsibility of the National Forest Institute within the Ministry of the Environment and Natural Resources. The National Council for Protected Areas (CONAP) has a role in mangrove management when mangroves are located in protected areas (Table 1). Protected areas are co-managed by CONAP and local NGO's and these organizations assume the day to day responsibilities of the protected areas. The majority of mangroves within Guatemala (88.2%) are located within the two protected areas (Table 2; Fig. 2).

The responsibility of mangroves in Honduras resides with the Department of Fisheries under the Secretariat of Energy, Natural Resources, Natural Environment and Mines, and local municipal environmental units have a role in mangrove management within their jurisdiction. Within protected areas, mangroves receive additional management from the Conservation and Forest Development, Protection and Wildlife Institute and local NGO's. The NGO's assume the day-to-day responsibilities of the protected areas. A total of 13 protected areas have been declared that have mangroves within their boundaries, however limited mangrove cover data is available, which precludes an accurate estimation of mangrove coverage within Honduran protected areas (Table 2).

3.3. Threats to mangroves

A total of 81 peer-reviewed articles focusing on mangroves were

Table 1
Legislation, agreements and protection of mangroves in the Mesoamerican reef region.

Mangrove Legislation		**Mexico**	**Belize**	**Guatemala**	**Honduras**
Legislation		General Wildlife Act 2000, Article 60.	Forestry Act 1989, Article 52. Forests Act Chapter 213, revised in 2003	Forestry Act 1996, Article 35.	Fisheries Act 1959, Article 52.
		It is prohibited to remove, transplant, prune or conduct any work or activity that may affect the integrality of the hydrological flow of mangroves.	Dredging and landfill is strictly prohibited unless there is significant benefit to the general population. Three types of permits can be issued for the alteration of mangroves, depending on the area of mangrove to be altered. Permits can be denied.	Change of land use of mangrove ecosystems is prohibited. By-law Resolution No. 01.25.98, Article 15 allows family consumption to a maximum of 5 $m^3 yr^{-1}$	The removal and cutting of mangroves is prohibited.
State ownership of mangroves		100%	30%	100%	100%
Government Agencies					
Government hierarchy for the management of mangroves	*Ministry*	Secretariat of the Environment and Natural Resources	Ministry of Agriculture and Fisheries	Ministry of the Environment and Natural Resources	Secretariat of Energy, Natural Resources, Natural Environment and Mines
	Department	Department of Ecology and Environment; Institute for Flora, Fauna and Culture	Department of Forestry	National Forest Institute	Fisheries department
	External departments		Coastal Zone Management Authority and Institute; Department of Fisheries	National Council for Protected Areas	Institute for Conservation and Forest Development, Protected Areas and Wildlife
	Other Agencies Non-government organizations	National Commission for Protected Natural Areas e.g. Comunidad y Biodiversidad Asociacion Civil; Amigos de Sian Ka'an	e.g. Belize Association of Private Protected Areas; Toledo Institute for Development Environment	National Council for Protected Areas e.g. Fundación para el Ecodesarrollo y la Conservación	Local Municipal Environment Units e.g. Bay Island Conservation Association; Roatan Marine Park
International and Regional Agreements					
Cartagena Convention (*Signatory only)		1985	1999	1989	1983*
Wetlands Convention (Ramsar)		1986	1998	1990	1993
Tulum Agreement		1995	1995	1995	1995
Mesoamerican Barrier Reef System Project		1997	1997	1997	1997
Central American Policy for the Conservation and Rational Use of Wetlands		N/A	2002	2002	2002
Ramsar Regional Initiative for the Integral Management and Wise use of Mangroves and Coral Reefs		2009	–	2009	2009
Ramsar Caribbean Wetlands Initiative		–	2009	–	–

Table 2
Protected areas of the Mesoamerican Reef ecoregion with mangroves within their borders.

	MPA/NP	Ramsar site	Management plan	Reference
Mexico (n = 13)				
Área de Protección de Fauna y Flora Yum Balam	X	X	Y	(CONANP, 2013)
Parque Nacional Isla Contoy	X	X	Y	(SEMARNAT & CONANP, 2015b)
Manglares de Nichupte		X	Y	(SEMARNAT & CONANP, 2014)
Parque Nacional Arrecifes de Puerto Morelos	X	X	Y	(SEMARNAP, 2000a)
Manglares y humedales del norte de la isla Cozumel		X	Y	(SEMARNAT, 2014)
Parque Marino Nacional Arrecifes de Cozumel	X	X	Y	(SEMARNAP, 1998a)
Playa Tortuguera X'Cacel-X'Cacelito		X	–	
Reserva de la Biósfera de Sian Ka'an	X	X	Y	(SEMARNAT & CONANP, 2015a)
Reserva de la Biósfera Banco Chinchorro	X	X	Y	(SEMARNAP, 2000b)
Parque Nacional Arrecifes de Xcalak	X	X	Y	(CONANP, 2004)
Parque Marino Nacional Punta Occidental Isla Mujeres, Punta Cancun y Punta Nizuc	X		Y	(SEMARNAP, 1998b)
Área Marina y Costera Protegida Actam Chuleb	X		–	
Zona Sujeta de Conservación Ecologica Santuario Manati Bahia Chetumal	X		–	
Total:	*10*	*10*	*10*	
Belize (n = 14)				
Bacalar Chico National Park and Marine Reserve	X		Y	(BFD, 2004)
Laughing Bird Caye National Park	X		Y	(BFoD, 2010)
Payne's Creek National Park	X		–	
Sarstoon-Temash National Park	X	X	Y	
Shipstern Conservation & Management Area	X		Y	(PACT, 2016)
Corozal Bay Wildlife Sanctuary	X		–	
Swallow Caye Wildlife Sanctuary	X		–	
Half Moon Caye Natural Monument	X		Y	(BAS, 2007)
Caye Caulker Marine Reserve	X		Y	(BCZMIA & BFD, 2004)
Gladden Spit and Silk Cayes Marine Reserve	X		Y	(BFD, 2010a)
Glover's Reef Marine Reserve	X		Y	(BFD, 2007)
Hol Chan Marine Reserve	X		Y	(BFD, 2002)
Port Honduras Marine Reserve	X		Y	(BFD, 2012a)
Sapodilla Cayes Marine Reserve	X		Y	(BFD, 2010b)
South Water Caye Marine Reserve	X		Y	(BFD, 2009)
Turneffe Atoll Marine Reserve	X		Y	(BFD, 2012b)
Total:	*15*	*1*	*12*	
Guatemala (n = 2)				
Reserva de usos multiples rio Sartsun	X	X	Y	(CONAP, 2009)
Punta de Manabique	X	X	Y	(CONAP, 2011)
Total:	*2*	*2*	*2*	
Honduras (n = 13)				
Parque Nacional Sistema de Humidales de Cuyamel – Omoa	X	X	–	
Parque Nacional Jeannette Kawas	X	X	Y	(ICF, 2012a)
Refugia de Vida Silvestre Punto Izopo	X	X	Y	(ICF, 2012b)
Sistema Humedales Laguna de Zambuco		X	–	
Refugio de Vida Silvestre Cuero y Salado (Barras de Cuero y Salado)	X	X	Y	(ICF, 2011)
Parque Nacional de las islas de la Bahia	X		Y	(IHT y ICF, 2015)
Zona de Proteccion Especial Marina Turtle Harbour – Rock Harboury el Sistema de Humedales de la Isla de Utila	X	X	Y	(IHT y ICF, 2012)
Zona de Protección Especial Marina Sandy Bay West End	X		–	
Parque Nacional Port Royal	X		–	
Monumento Natural Marino Archipielago Cayos Cochinos	X		Y	(CMCC, 2009)
Refugio de Vida Silvestre Laguna de Guaimoreto	X		–	
Reserva de la Biósfera del Rio Platano	X		Y	(ICF, 2013)
Laguna de Bacalar		X	–	
Total:	*11*	*7*	*7*	
Grand totals **43**	**38**	**18**	**31**	

identified within the MAR region. The majority of the research was conducted in Belize (68.2%), the remaining studies were conducted in Mexico (22.0%) and Honduras (9.8%). No peer-reviewed primary mangrove research identified from Guatemala. Of the 81 peer-reviewed articles identified, 15 of these address threats to mangroves (Ellison and Farnsworth, 1997; Feller et al., 1999; Cahoon et al., 2003; Piou et al., 2006; Mckee, Cahoon and Feller, 2007; McKee, Rooth and Feller, 2007; Taylor et al., 2007; Vaneslow et al., 2007; Granek and Ruttenberg, 2007; Carrillo-Bastos et al., 2008; Islebe et al., 2009; Macintyre et al., 2009; Mckee and Vervaeke, 2009; Hirales-Cota et al., 2010; McCloskey and Liu, 2013), a total of 8 different threats were classified. A total of 37 different threats, were identified from the 20 Ramsar sites, the majority of which were anthropogenic (90.7%), e.g. 'logging', 'aquaculture and coastal development' (Fig. 3). The majority of peer-reviewed mangrove research from the MAR region has focused on natural disturbances (71.4%) of mangrove systems (Fig. 3). These trends are not just a regional trend, but hold for each of the individual countries, where researchers and managers foci are on natural and anthropogenic disturbances, respectively (Fig. 3). Primary research interests include hurricanes and sea -level change, and Ramsar managers across the region are concerned with deforestation, agriculture, and development.

4. Discussion

Despite the stringent national legislation and international agreements which provide protection to mangrove forests, and the additional protection provided by the 43 protected areas (which contain mangroves), mangrove cover in the MAR declined by over 110,000 ha from 1990 to 2010, with an estimated current cover of 239,176 ha, equivalent to 1.7% of the world's mangroves (Giri et al., 2011). The greatest

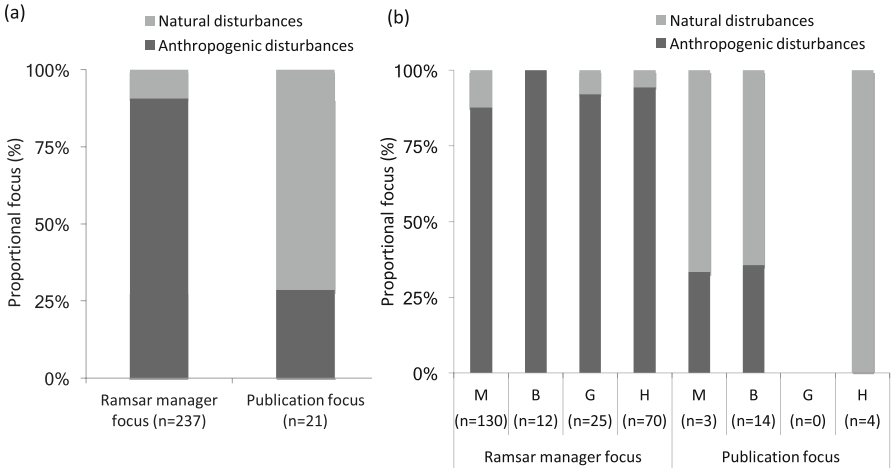

Fig. 3. Threats to mangroves of the MAR as identified by Ramsar managers and within peer-reviewed publications (a) throughout the MAR; and (b) individual countries: M – Mexico; B – Belize; G – Guatemala; and H - Honduras.

losses were observed in Mexico and Honduras. The decline in mangrove cover suggests a problem with enforcement. We suggest a lack of resources for enforcement, transparency within the governance framework, and lack of political will as potential reasons for the failure in the enforcement of mangrove legislation. The number of organizations responsible for the management and protection of mangroves in each country varies and causes confusion, with the exact role of each party unclear. Each country has a specific government department responsible for mangrove protection, with additional oversight from external agencies and non-government organizations (NGO's) when mangroves are located in protected areas. It must be noted that such discrepancies are not unique to mangrove systems or to this region (Rife et al., 2013). Limited national budgets of the four countries reduce governmental institutional capacity, which has resulted in civil society in the form of NGO's filling the void in the management of protected areas. NGO's assume an important role as co-managers of protected areas, fulfilling the day-to-day management duties. However, a lack of authoritative power and a lack of human capacity to physically patrol often large and remote areas, inhibits the ability of NGO's to enforce environmental legislation (Cudney-Bueno et al., 2009; Rife et al., 2013). In essence many of the protected areas in each of the four countries could be considered “paper parks”, as they provide no greater protection or management to mangroves than national legislation (Rife et al., 2013). It is important not to be too critical of these institutions, however, all of which are operating on limited resources. The focus should be on how to support and build capacity of these organizations to allow them to improve mangroves and natural resource management efficacy.

Geopolitical interests of the different countries have reduced collaborative efforts of mangrove protection. Despite the four countries sharing an ecoregion, significant geopolitical divisions exist. This is exemplified by Belize ratifying a separate Ramsar initiative to the other three countries. The paradox is that despite having the same or very similar objectives, the four countries are not working together to achieve these goals. A lack of collaboration and harmonization in how management strategies are developed and implemented can reduce mangrove protection, especially in forests that straddle international borders (McCallum et al., 2015). Belize is the only country where all of mangroves are within the boundaries of the MAR. In contrast Mexico and Guatemala have significantly greater mangrove cover on other coastlines, and a little more than half of the mangrove cover of Honduras is concentrated within the Gulf of Fonseca, on the Pacific coast. Threats to mangroves may vary significantly on the different coasts, and therefore influence how national mangrove legislation is developed, and how governments prioritize limited management resources. Regardless, greater collaborative efforts, such as the Mesoamerican Barrier Reef System Project, need to be established to promote the protection of marine resources, and facilitate transboundary initiatives that recognize that ecological populations do not align with geopolitical boundaries. There is a high probability that mangrove forests within the region are connected as recent studies have shown high levels of ecological connectivity in the MAR region for lobster, fish and corals (Butler et al., 2011; Truelove et al., 2015; Chollett et al., 2017).

Evidence based decision-making has been well documented as an important component of resource management (Christensen et al., 1996; Ruckelshaus et al., 2008). However, in the papers we reviewed there appears to be no discernible link between researcher recommendations and resource manager decision-making or actions. Concluding statements within articles may make some reference to conservation or management, but usually included no advice on how to apply research findings directly to management. Additionally, our study identified a disconnection between Ramsar site managers and the scientific community. Managers were primarily focused on localized anthropogenic threats (e.g. Macintyre et al. (2009)), while researchers focused on natural disturbances, such as hurricane events (Vaneslow et al., 2007) and the impact of sea-level change (Mckee, Cahoon and Feller, 2007). Both anthropogenic and natural threats have either had, or have, the potential to negatively affect mangrove cover, but the different foci of researchers and managers is likely to hinder progress in mitigating threats from either source.

It is crucial that researchers and managers increase their communication and work together to understand the full complexity of the threats to mangrove forests. Combining these different priorities could bring important benefits. For example, the identification of areas of mangrove forests resilient to climate change can focus management efforts and create local priority conservation zones where anthropogenic disturbances should be minimized. Both groups are focusing on important issues, however the assumed lack of dialogue between stakeholders precludes the integration of science into mangrove management plans. Cvitanovic et al. (2014) have reported similar disconnects in the management of coral dominant marine protected areas. They proposed knowledge brokers, boundary organizations, knowledge coproduction and management-orientated summaries in research articles as potential solutions to provide managers access to scientific outputs. The HRI program has put some of these in place within the MAR primarily focused on coral reefs, but these could be adapted to facilitate greater communications between managers to promote science lead mangrove management. In addition, discussion forums exist, such as the mangrove list (majordomo@essun1.murdoch.edu.au). List serves provide a forum where individuals can pose questions to experts in an

array of different fields and can provide useful dialogue between practitioners and researchers.

These potential solutions provide important links between peer-reviewed conservation science and conservation managers, but the dichotomy of researcher and manager foci must also be addressed. Combining current research interests of natural disturbances with local management concerns of anthropogenic stresses, in particular the understanding of local drivers of deforestation, is critical. However, if institutional capacity is lacking, then the implementation of management strategies will always be problematic. Building capacity within and among government departments and NGO's to ensure the effective enforcement of legislation and promote links with the scientific community to facilitate science-based decision-making is vital for the management of mangroves in the MAR, and elsewhere. It is important that managers have access to and make use of current research, especially when developing management plans (Adeel and Pomeroy, 2002; Iftekhar and Islam, 2004; Schmitt and Duke, 2015). There is also an onus on researchers to increase the availability of their research to management authorities, not just government agencies, potentially through regional online archives or data repositories. Additionally, researchers should engage managers prior to conducting their research to foster a dialogue that can promote mangrove management and conservation efforts. Promoting public awareness to garner political will is also important, and a greater understanding of the ecosystem services provided by mangroves to local communities and their inclusion in management has the potential to increase the protection and conservation of mangroves (Shunula, 2002; Sudtongkong and Webb, 2008; Datta et al., 2012).

We propose the following recommendations to promote management of mangroves within the region:

(1) Coordinated and detailed mapping projects in Belize and Honduras to provide more recent estimates of mangrove cover that can be used to set baselines from which management actions can be monitored and assessed;
(2) The implementation of a systematic, harmonized, mangrove monitoring protocol throughout the region that will facilitate comparisons of mangrove forest status;
(3) A program of work to increase understanding of the connectivity of mangrove populations throughout and beyond the MAR ecoregion, which can then be used to identify areas where greater collaborations are needed;
(4) The creation of a repository of scientific literature of the region to which researchers can submit their research, making it available for practitioners in the region and providing another step towards an increased dialogue between managers and the scientific community.

Our proposals require coordination and management of resources and information across the MAR. The HRI program already brings together stakeholders from across the region, but at present is heavily coral reef focused. Mangrove coverage was a key indicator within the original HRI guide (McField and Kramer, 2007), and therefore could become part of the biennially produced report card, which provides stakeholders an update on the status of marine resources. Our suggestion is that the network of contacts and collaborations within this program could be used to facilitate more coordinated monitoring and assessment of mangroves and seagrass ecosystems in the region.

5. Conclusion

The stringent national legislation and international agreements which should provide protection to mangrove forests within the MAR are ineffective. A number of local anthropogenic stressors threaten mangrove forests, and despite comprehensive legislation, mangrove cover has declined in all four countries. Capacity building of government and non-government institutions is required, as a lack of capacity has reduced environmental regulation enforcement. Local anthropogenic stressors are of greatest concern to managers of protected areas, whilst scientific research is focused on natural disturbances, primarily climate change. These different focuses can be advantageous if they can be linked effectively. For example, the identification of climate change resilient mangrove forests can channel mangrove management efforts to maximize effectiveness of limited resources. Greater understanding of drivers of local anthropogenic threats to mangroves is required to provide managers with the necessary tools to reduce these threats and promote mangrove forests and the ecosystem services they provide. To promote successful management, we suggest the reinforcement of institutional capacity, enhance links between government departments and civil society and increase science-based decision-making within protected areas management plans.

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Appendix A. Supplementary data

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